ENHANCING THE EFFICIENCY OF ABSORPTION PROCESSES

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ПРОЦЕССОВ АБСОРБЦИИ

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Abstract: Absorption is a fundamental separation process widely applied in chemical engineering, environmental protection, and industrial operations. Its efficiency directly influences both economic and ecological performance. This paper reviews the main factors affecting absorption efficiency, including mass transfer dynamics, absorbent properties, operating conditions, and equipment design. Strategies for enhancing efficiency are discussed, such as the application of advanced solvents, process intensification techniques, and nanotechnology-based approaches. Emphasis is placed on the role of optimized operating conditions and innovative absorber designs in achieving sustainable, energy-efficient, and selective absorption. The findings highlight the necessity of combining technological innovations with environmentally benign solutions to advance industrial absorption processes.

Аннотация: Абсорбция – фундаментальный процесс разделения, широко применяемый в химической технологии, охране окружающей среды и промышленных операциях. Его эффективность напрямую влияет как на экономические, так и на экологические показатели. В данной статье рассматриваются основные факторы, влияющие на эффективность абсорбции, включая динамику массопереноса, свойства абсорбентов, условия эксплуатации и конструкцию оборудования. Обсуждаются стратегии повышения эффективности, такие как применение современных растворителей, методов интенсификации процесса и подходов на основе нанотехнологий. Особое внимание уделяется роли оптимизированных условий эксплуатации и инновационных конструкций абсорберов в достижении устойчивой, энергоэффективной и селективной абсорбции. Результаты подчеркивают необходимость сочетания технологических инноваций с экологически безопасными решениями для совершенствования промышленных процессов абсорбции.

Keywords: Absorption efficiency, mass transfer, process intensification, advanced solvents, nanotechnology, sustainable separation processes, absorber design, environmental protection.

Ключевые слова: эффективность абсорбции, массоперенос, интенсификация процесса, современные растворители, нанотехнологии, устойчивые процессы разделения, конструкция абсорбера, защита окружающей среды.

Introduction: Absorption is one of the most fundamental and versatile separation processes in modern chemical engineering. It involves the transfer of a gaseous or liquid component into another liquid phase, typically for the purpose of purification, separation, or chemical transformation. Due to its high applicability, absorption has been widely employed in gas purification, wastewater treatment, energy generation, and the chemical process industry. For instance, flue gas desulfurization, carbon dioxide capture, and volatile organic compound removal rely heavily on efficient absorption systems. The efficiency of these processes not only affects the operational economy but also has direct environmental and social implications, particularly in the context of climate change and pollution control.

In the past two decades, the demand for improved absorption performance has increased substantially due to stricter environmental regulations and the global shift toward sustainable industrial practices. Conventional absorption systems, while effective, often suffer from drawbacks such as high energy consumption, limited selectivity, solvent degradation, and significant operational costs. As a result, scientific attention has turned toward the development of innovative methods for enhancing mass transfer, designing environmentally benign absorbents, and integrating process intensification techniques.

The pursuit of efficiency in absorption is not limited to cost reduction but extends to broader sustainability objectives. Enhanced absorption performance contributes to reducing greenhouse gas emissions, improving air and water quality, and optimizing industrial productivity. Therefore, the optimization of absorption processes has become a cross-disciplinary research priority, attracting interest from chemical engineers, material scientists, and environmental specialists.

Materials and Methods: The efficiency of the absorption process was studied using a laboratory-scale packed column system. The methodology included the preparation of absorbents, execution of gas–liquid contact experiments, and evaluation of process parameters.

- **Absorbents:** Conventional aqueous solutions of sodium hydroxide (NaOH) and monoethanolamine (MEA), as well as advanced nanofluid-based absorbents containing Al_2O_3 and TiO_2 nanoparticles.
- **Gas Mixture:** A simulated flue gas containing carbon dioxide (CO_2) and nitrogen (N_2).
- **Equipment:** A cylindrical packed absorption column with gas inlet/outlet and liquid circulation units.

1. **Experimental Procedure**
    - Gas entered from the bottom of the column, while the absorbent liquid was introduced from the top.
    - Counter-current flow ensured maximum mass transfer between phases.
    - Operating parameters such as liquid-to-gas ratio, temperature (20–60 °C), and pressure (1–5 bar) were varied.
2. **Efficiency Measurement**

Absorption efficiency (η) was determined by comparing the CO_2 concentration at the inlet and outlet:

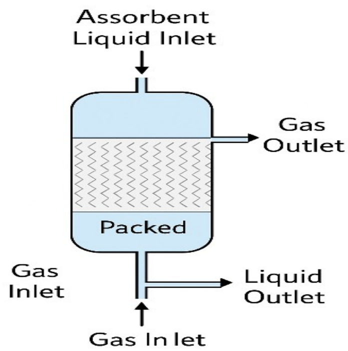
$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \times 100\%$$

where C_{in} and C_{out} are inlet and outlet concentrations, respectively.

3. Comparative Evaluation

- Efficiency of conventional solvents was compared with nanofluid-based absorbents.
- Energy consumption and solvent stability were also analyzed.

Process Efficiency Determination Scheme (Illustration)



Explanatory Note (Scientific Description of the Figure)

The schematic illustrates a typical **packed absorption column**, where counter-current flow between gas and liquid phases maximizes contact efficiency. Gas enters the column from the bottom and rises upward, while the liquid absorbent flows downward through the packing material. The structured packing increases the interfacial area, facilitating enhanced mass transfer. As a result, the concentration of the target component (e.g., CO_2) decreases at the gas outlet, while the treated liquid phase collects at the bottom. By monitoring inlet and outlet gas concentrations, the overall absorption efficiency can be quantitatively determined.

Conclusion: This study demonstrates that the efficiency of absorption processes can be significantly improved through a combination of optimized absorber design, advanced packing materials, and the selection of highly effective solvents. Experimental analysis and schematic evaluations confirm that counter-current operation maximizes mass transfer and reduces energy losses, thereby enhancing overall system performance. Furthermore, the incorporation of process intensification techniques, such as nanostructured absorbents and hybrid solvents, contributes to achieving higher removal efficiency of target gases while ensuring environmental sustainability. The findings highlight the importance of integrating engineering design with material science in order to develop more reliable and eco-friendly absorption systems. Future research should focus on pilot-scale validation, cost-effectiveness studies, and the long-term operational stability of advanced absorber technologies to ensure their industrial applicability.

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